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**SATELLITE IMAGERY AND  
REMOTE SENSING METHODOLOGY:  
APPLIED TO CHANGE DETECTION ALONG FOUNTAIN CREEK**

**by**

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## **ABSTRACT**

Remote sensing methodology and GIS technology provide the resources needed to gain an improved understanding of the Earth as a system. Worldwide population growth and development amplify the naturally occurring changes on the Earth's surface and give birth to new types of changes. With the help of remote sensing technology, the energy radiated by surface features or reflected off the Earth's surface by the sun can be used to map the land and trace the changes that take place over time. GIS technology can then be used to integrate large amounts of image data and other related details about an area to analyze the changes and their origin.

This paper discusses the methodology and analytical techniques used to process digital images with a focus on change detection processes. It also emphasizes many of the atmospheric affects that must be considered before analysis can begin or inferences can be made. In addition, a change detection analysis of a region of Fountain Creek in Colorado Springs is performed using LANDSAT TM images gathered in 1993, 1994, and 1997. The analysis provides an example of the application of many of the techniques initially discussed and also highlights the cautions that were taken to avoid false conclusions. The investigation includes the generation of change detection images produced using image algebra and change vector analysis.



## NOMENCLATURE

C-CAP	Coastal Change Analysis Program
DEM	Digital Elevation Model
DN	Digital Number
FCWP	Fountain Creek Watershed Project
GCP	Ground Control Point
GIS	Geographic Information System
IFOV	Instantaneous Field of View
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
TM	Thematic Mapper
USGS	United States Geological Survey

## INTRODUCTION

Humans have roamed the Earth for many years, forming habitats and experiencing, if not causing, an innumerable amount of changes in the Earth's surface features. Thus, it is only natural to wonder how the surface changes and to analyze the occurrences and causes of that change.

The integration of remote sensing and GIS technology provides a unique and effective method of monitoring and analyzing the changes that occur on the Earth's surface. While some features remain relatively stable over time, much of the Earth's surface constantly changes due to natural processes or man-made disturbances. Therefore, an accurate and consistent inventory of the changes, in the form of images, helps illustrate the dynamics of the change and clarifies its source. A multitude of information gathering tools and analysis techniques exist to perform investigations of the physical processes at work. Images can be created to facilitate the evaluation of deforestation, desertification, contamination, and erosion and help clarify the possible causes of such change. Furthermore, the information gathered from remotely sensed images aids the decision-making processes related to crop yields and health, land use, project site evaluation, forest management, and hydrology. These research techniques provide one focus of this investigative report. This paper also demonstrates the use of several of these techniques as they apply to the analysis of the erosion along Fountain Creek.

## BACKGROUND

### *Erosion and the Fountain Creek Watershed*

The Fountain Creek region of Colorado is one of many areas in the United States and foreign nations that faces challenges due to flooding and erosion. As a result of the concerns, several government and private organizations have been developed to improve the management of streams, rivers, and floodplains, and to pursue the restoration of such areas when and if possible. The Interagency Floodplain Management Committee and the Coalition to Restore Aquatic Ecosystems are examples of such organizations. In addition, local advocacy groups for rivers and streams have surfaced, such as River Watch in Illinois and the Stream Teams in Missouri, and now receive funding and technical assistance from regional or state programs. Likewise, the Fountain Creek Watershed Project, made up of concerned residents, professionals, and government officials, currently works to resolve the issues created by the Fountain Creek transformation.

Like the Fountain Creek area, numerous countries worldwide suffer from the challenges related to watersheds. The following two examples demonstrate the prevalence of the problem worldwide and the similarity of the underlying causes as compared to Fountain Creek. The first case occurs in the Jhiku Khola watershed in Nepal. The problems of the Jhiku Khola watershed originate with its erosion prone red soil, typical of the Middle Mountains. On top of that, increased farming and grazing, and influx of migrants during the monsoon season augment the dilemma. The presence of human activities in the area causes soil erosion, sedimentation, deforestation, and a reduction in the fertility of the soil. [1]

Similarly, a study of the Missouri River Floodplain, conducted in 1983, concluded that the many human activities in the floodplain contribute to the damage that the area encounters. Bank stabilization and navigation structures along the river constrict the floodplain and lead to the accretion of land along the channel. Furthermore, development projects and highway and railway embankments in the floodplain introduce unnatural environmental conditions that magnify the flooding and erosion problems. [2]

The cases above introduce three of the major factors contributing to the watershed dilemma—growing populations, forest clearing, and land development. These interrelated circumstances send large amounts of sediment and other pollutants into the waterway and facilitate the process of erosion. A quantitative analysis of this relationship shows that once ten percent of a watershed (particularly the upper region) is paved over or compacted, the waterway progressively degrades. The river channels are cut deeper and deeper by increased water loads and flooding becomes more frequent [3]. These same factors are exactly what make Fountain Creek “one of the worst creeks in the state [of Colorado] for bank erosion [4].”

The city of Colorado Springs and the surrounding area, including the Pikes Peak region and extending south towards Pueblo, has undergone a transformation in recent years leading to a magnification of the erosive processes along Fountain Creek. Before the 1950's, when there were fewer people and fewer developed areas, Fountain Creek flowed for part of the year, drying up late in the summer and staying dry during the winter. Now, the creek flows nonstop. It started rising as a result of more water flowing into the creek from booming development, more paved streets and accompanying drainage systems, and increasing amounts of household water pumped into the area [4].

Increased rainwater and the region's fragile sandy soils add to the dilemma. Currently, the water flowing through Fountain Creek carries approximately 70 truckloads of sediment into the Arkansas River daily. The creek's water flow has the power to rip soils from its banks and its bottom, as well as destroy pipelines, trails, homes, bridges, roads, and railroad tracks. In fact, the creek's path can move up to 100 feet per year in some places, leading to immeasurable damage. [4] Table 1 provides an example of the results of a quantitative analysis of the Fountain Creek watershed erosion performed by USGS. Note the increase in the total streambank erosion during successive periods.

Period	Number of years between photographs	Total streambank erosion (feet)	Average streambank erosion rate (feet per year)
1947-60	14	68	4.9
1961-66	6	67	11.2
1967-75	9	74	8.2
1976-83	8	117	14.6

**Figure 1. USGS Fountain Creek Watershed Erosion Analysis Results [5]**

Depending on the point of view, the forces at work in the Fountain Creek Watershed can be seen as both destructive and beneficial. For the agricultural community attempting to farm in the watershed and industries, such as the railroad and water companies with assets located in the area, the erosive processes create problems that require expensive solutions. Yet, in other regions of the watershed, the flooding and erosion provide the necessary soil and nutrient conditions for the healthy growth of trees downstream. A cumulative analysis of the areas of the watershed that demonstrate the most change can help generate management and prevention techniques that will benefit each of those entities affected by the watershed

Controversy over how to deal with watershed issues arises from the numerous individuals affected by the disastrous flooding and erosion and the economic predicament that ensues. In one case, 201 farmers in the Minnesota River watershed were paid a total of \$7.6 million after the floods in 1993 to convert 9200 acres of their low lying farmland into permanent conservation easements. Now the land that was once planted in crops is covered with grasses and trees that are less vulnerable to erosion and, hence, the risk of expensive losses has been greatly reduced [6]. Regardless, the government had to dish out a large sum of money to correct the problem. In the case of Fountain Creek, a gas company spent \$500,000 trying to protect a pipeline from bank erosion, but eventually had to remove it. Likewise, a railroad company spent \$500,000 to rebuild a creek bank after water eroded the track's supporting soil. These examples clearly illustrate the economic burden and hardship that some industries face in regions like the Fountain Creek Watershed, but how to resolve the problems remains a mystery.

Many proposals have been made to suggest methods for curbing the erosion along rivers and creeks. Two of these include lining the creek with boulders and trees, and building expensive reservoir systems to help reduce the abrupt flow of stormwater into the creek. The planting of trees along riverbeds has been tried and proven worldwide. The network of roots that trees provide helps control erosion and removes excess nutrients and sediments from incoming groundwater [7]. Unfortunately, in the case of Fountain Creek, the results were not so impressive. Tom Johnson, director of FCWP, planted trees along a portion of the creek to test the feasibility of the option. He chose a type of tree that develops extensive root systems and grows unusually quickly, hoping that the trees would withstand the creek's power and stabilize the fragile soils. However,

the trees could not combat the compound forces present along Fountain Creek. Likewise, while placing boulders along the creek's edge protects the immediate stream bank from strong currents, future problems arise when the water inevitably displaces the boulders. Flowing water then bounces off the large objects in its path, giving it more energy and causing more intense erosion downstream [4]. Other preventative techniques that have been suggested, such as lining the creek with concrete, also prove to be either more destructive or impractical. Hence, the search for a steadfast solution continues.

Investigations such as this one may set a foundation to help prevent any further wastes of money and resources due to the erosive processes in watershed regions. Consequently, the FCWP hopes to benefit from the results of this study by gaining more insight into their problem and bringing them one step closer to a possible solution. In addition, the scientific community may be interested in the results of this investigation as it provides another example of the information that can be derived by integrating remotely sensed images with GIS technology.

### ***Remote Sensing***

Remote sensing is defined as the process of obtaining information about an object by acquiring data with a device that is not in contact with that object [8], e.g. satellites, cameras, the human eye. Before the advent of remote sensing, there was no efficient method of gathering a clear, consistent record of ground features and observable surface changes. Yet, satellite imagery and aerial photography now provide the means to make comparisons of images over time.

Both the remote sensing methodology and the imagery data offer several benefits when used as analytical tools for the study of the Earth's changing surface features. First,

satellites provide the vehicle necessary to carry large sensors over large coverage areas on a repetitive basis. This means that satellite imagery is internally consistent through time--the same location can be re-examined by a sensor at different known intervals [9], depending on the satellite's orbit. This repetitive coverage permits the tracking of changes over a desired region or time frame. Furthermore, simulation models such as ADAPT and WEPP, which were often used in the past, get the job done, but are time consuming, labor intensive, and costly [10]. The simulation models also require destructive sampling to acquire ground truth data. Remote sensing techniques, on the other hand, provide fast, low cost information and are non-destructive; although ground sampling may improve analysis, it is not required. Furthermore, the wide-area coverage of satellites is a particularly important advantage when studying large areas, such as lengthy waterways. All in all, remote sensing technology cuts data-gathering costs and improves forecasting of long-term consequences of urban development [11]. As a result, many county and state governments currently use LANDSAT and SPOT satellite data for change analyses.

There are two types of remote sensing data that can be gathered: active and passive. Active remote sensing involves the use of radar satellites. A radar satellite sends a known signal to Earth and then another sensor on board the satellite measures the return signal, which it uses to create a map of ground features. On the other hand, passive remote sensing equipment measures incoming energy reflected from the sun off an object or the energy emitted by the object itself to create an image. Since all objects emit electromagnetic energy, passive remote sensing provides an efficient means of



gathering spectral data and will be the type of data used in the investigation of Fountain Creek.

Besides the type of data, three attributes of remote sensing systems must be considered to determine the most advantageous system for a given analysis. (1) *Spatial resolution* is the level of detail or the size of the smallest identifiable object. Present sensors for use by the public generally provide between 30-meter and 4-kilometer resolution. Most of the imagery used in this study has 30-meter resolution. (2) The number of different colors or parts of the spectrum that a system measures defines its *spectral coverage*. Today's systems are capable of supplying one to seven measurements. Since electromagnetic energy measured at different wavelengths reveals more details than only visible light, multispectral satellite images are often preferred over aerial photographs. As such, this study will use LANDSAT multispectral images. (3) *Temporal frequency* describes how often a sensor collects data over the desired region. Current systems' cycles range from one image per month to two images per day. [8] The imagery from the LANDSAT TM sensor will be the primary sensor of concern for the remainder of the report since the Fountain Creek analysis employs such data.

The LANDSAT TM sensor was designed to improve upon the shortcomings of the LANDSAT MSS equipment. The TM sensor images a 185 kilometer swath and returns to a given area every 16 days. Furthermore, LANDSAT TM images provide 30-meter ground resolution, except for the thermal band which has a resolution of 120-meters. More importantly, TM sensors provide information from seven different spectral bands. The wavelength range and location of the bands were chosen to improve the capability to discriminate between major Earth surface features. Table 2 shows the

spectral bands of the Thematic Mapper and their principal applications. In addition, the TM equipment performs an analog-to-digital signal conversion using a 256 digital number range (eight bits). This improvement increases the gray scale range by four times as compared to the 64 digital number range (six bits) used by the MSS sensor. The TM's larger gray scale range means that it can represent surface features with finer distinctions in color, permitting the observation of more subtle changes.

Band	Wavelength (um)	Nominal Spectral Location	Principal Applications
1	0.45 – 0.52	Blue	Designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping, and cultural feature identification.
2	0.52 – 0.60	Green	Designed to measure green reflectance peak of vegetation for vegetation discrimination and vigor assessment. Also useful for cultural feature identification.
3	0.63 – 0.69	Red	Designed to sense in a chlorophyll absorption region aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76 – 0.90	Near-Infrared	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination.
5	1.55 – 1.75	Mid-Infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.
6	10.4 – 12.5	Thermal Infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.
7	2.08 – 2.35	Mid-Infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.

**Table 2. Thematic Mapper Spectral Bands** (reproduction) [12]

While remote sensing technology provides an immense amount of information about the Earth's surface, geographically referenced field data, or ground truth, can enhance the analysis with the help of a GIS. High resolution aerial photography and field samples can expose valuable information that may be hidden from satellite sensors due to

their altitude. As such, the combination of ground truth data with satellite imagery often delivers the most integrated and accurate analysis approach [13]. Externally gathered data can be entered into a GIS along with the imagery data. For that reason, a GIS allows for easy synthesis of the interrelated data and provides an effective means of analysis.

### ***Geographic Information Systems***

Traditionally, analysts attempting to understand the dynamic relationship between different components of the environment used a manual overlay process as their analysis tool. This process uses maps and transparencies as visual representations of the data [13]. Then, by overlaying the graphically represented data, analysts make guesses as to which factors demonstrate an influence on one another. However, the growth of environmental awareness and a desire to protect our natural resources led to the development of the GIS. A GIS "represents the point where geography, math, and electronics meet and combine to catalogue, superimpose, examine and visualize...phenomena to assess their impact in space and time" [1]. Geographic information systems unite remote sensing data, Earth survey data, and cartography and can generate new maps using algorithms and automated processes. In addition, because GISs can manipulate various layers of information [9], they aid in the identification of related constituents.

Digitized images can be entered into a GIS to facilitate an analysis. While digital image analysis techniques and algorithms reduce human labor and improve consistency, there are still some sources of possible error or misinterpretation that must be considered. For example, a drawback of digital images produced by both LANDSAT and SPOT is that their sensors are unable to penetrate cloud cover [14]. What this means is that the images do not necessarily represent the true value of any surface features below clouds or

in a cloud's shadow. Therefore, the data must either be corrected to account for clouds in the image, or the analysis must not consider areas affected by cloud cover. Hence, while GIS help integrate and analyze information, the outcomes are only as accurate as the data that is used to build the system and, thus, care must be taken not to accept the results as gospel.

### ***Image Considerations for Change Detection***

Change detection involves the comparison of two or more image data sets. While some analysis may be performed using raw data, many applications often demand a careful data transformation before an accurate analysis can be made. The ideal change detection system would exhibit constant temporal, spatial, spectral, environmental, and radiometric factors. However, since ideal situations rarely occur, geometric correction and radiometric normalizing must be performed to avoid inducing false change calculations due to poorly registered images or other factors such as differential path radiance and sun angle variations.

The temporal resolution of the images involved in a change detection should maintain two constants: the time of day of the image and the season. Ensuring that the images are taken at generally the same time of day eliminates sun angle effects that can alter the reflectance properties of some features. LANDSAT data is acquired before 9:45 a.m. for most of the United States. Also, acquiring images on anniversary dates each year, or corresponding days and months of the year, removes seasonal sun angle differences and helps eliminate climatic and agricultural differences. [15]

The spatial resolution and look angle must also be held constant for an effective change analysis. The instantaneous field of view, or region that can be seen at any one

time by the satellite sensor, must be the same on each date. LANDSAT TM data maintains a 30 x 30-meter resolution. Images are easier to register to one another if they maintain the same resolution. Data obtained from two different sensor systems can be analyzed together, but the data from both images must be resampled to get a uniform pixel size. Moreover, the off nadir look angle should be the same for change analysis images—otherwise, as with the temporal requirement, any large variation in look angle will result in different reflectance properties. [15]

In addition, since change detection techniques generally rely on the spectral characteristics of images to perform the analysis, the spectral bands used in the analysis must correspond. “A fundamental assumption of digital change detection is that there should exist a difference in the spectral response of a pixel on two dates if the biophysical materials within the IFOV have changes between the dates” [15]. Each sensor system, whether it be LANDSAT, SPOT or any other system, may record energy in different portions of the electromagnetic spectrum. If images produced by different sensors are used for the change detection, bands that measure approximately the same wavelength of energy must be matched for comparison. LANDSAT MSS images display information from four broad bands. SPOT HRV sensors use three coarse multispectral bands and one panchromatic band. LANDSAT TM sensors measure energy from six narrow optical bands and one thermal broad band. Despite their differences, images from each of these sensor systems can be used together as long as corresponding spectral bands are utilized for the analyses. [15]

Special concern must also be given to certain environmental, atmospheric, and surface characteristics when performing change detection analyses. A clear

atmosphere—no haze, clouds, or extreme humidity—provides the most optimum conditions for accurate change detection. Identical soil moisture conditions are also ideal. Extreme differences in wetness or dryness can cause serious misinterpretations—water in either soil or vegetation alters their spectral reflectance, particularly in the infrared. Attempting to choose images from anniversary dates and to review precipitation records provides the most effective method of eliminating error caused by environmental characteristic differences. [15]

### ***Image Processing for Change Detection***

Once the remote sensor data is selected and a classification scheme is chosen, the data can be processed for change information. The change detection procedure involves geometric and radiometric correction, change detection algorithm(s), classification (if necessary), creation of change detection products, and an error evaluation (if one can be applied). While raw data can be used, usually raw digital images contain distortions that render them useless without correction. The sources of the distortions range from variations in altitude, attitude, velocity, panoramic distortion, curvature of the Earth, refraction, and relief displacement. Geometric and radiometric corrections are used to compensate for distortions to generate more reliable data. Each of these techniques will be described in the following paragraphs.

Geometric correction can be implemented for two different types of distortions in images: systematic, or predictable, distortion and random distortions. An example of the first type of distortion would be the skew distortion present in satellite imagery. Due to the eastward rotation of the Earth, each sweep of the satellite over a given area will be slightly to the west of the previous sweep. Thus, each successive image has a minor

offset that must be corrected before an accurate analysis can be made. This type of systematic offset is easily correctable using mathematical relationships.

Ground control points provide a basis for correcting random distortions. Ground control points are "features of known ground location that can be accurately located on the digital imagery" [12], such as buildings, highway intersections, and distinct shorelines. A least squares regression analysis is accomplished using the GCPs digital coordinates and their known geographic coordinates. The result of the least squares yields the coefficients of the coordinate transformation equations necessary for realigning the distorted image [12]. The Fountain Creek analysis will also demonstrate how GCPs can be used for registering or aligning different images to one another.

Depending on the application at hand, radiometric correction may be necessary if the radiance measured by the sensor varies due to scene illumination, atmospheric conditions, viewing geometry, or inaccurate instrumentation. The radiometric correction technique presented here provides an example of how to correct for the change in reflectance of ground features at different times or locations [12]. First, the brightness of each pixel is calculated based on a zenith sun angle for each image. Then, each pixel is divided by the sine of the solar elevation angle for the appropriate time and location of a given image to provide a better representation of the true radiance. Again, this simple technique specifically accounts for seasonal variations in the sun angle.

Several resampling algorithms can also be used to correct multi-date data: bilinear interpolation, nearest neighbor, and cubic convolution. Each of these methods provides a means for registering imagery data in a GIS and can be used to prepare multi-

date images for overlay analysis. The algorithms are described in the following paragraphs.

The popularity of the nearest neighbor technique emanates from the simplicity of its calculations. This algorithm assigns any unknown pixel the value of the closest pixel in the sampling grid. This method of reassignment retains the original pixel brightness values throughout the transformation of the image. However, the algorithm can produce images with less precise spatial correlation than cubic convolution, and may contain a spatial offset of up to  $\frac{1}{2}$  pixel [12]. Nevertheless, C-CAP recommends the nearest neighbor technique [15], probably because of its simplicity and preservation of pixel brightness.

Of the three resampling techniques, cubic convolution employs the most complicated process. The process uses a 16-pixel matrix surrounding the pixel in question to generate an average value. This resampling method generates sharper images, but unfortunately loses accuracy by averaging pixel brightness.

Like cubic convolution, bilinear interpolation has the disadvantage of averaging pixel brightness—the algorithm uses a distance-weighted average of the values of the four nearest pixels to assign pixel brightness. The resampled images have a smoother looking appearance, however the averaging technique alters the contents of the original image. Yet, bilinear interpolation does offer more simplicity than cubic convolution.

### ***Change Detection Techniques***

In general, change detection can be defined as a process of identifying variations in the condition of objects or phenomena by observing the items at different times. In remote sensing, change detection relies on radiance values to change in order to identify



significant change in the features of the image. The focus of this study involves the use of satellite imagery for change detection. A number of approaches have been developed to accomplish this task. The following list names seven of the most common and useful change detection algorithms: write function memory insertion, multi-date composite image, image algebra, post-classification comparison, binary mask, ancillary data, manual (on-screen) digitization. The needs of the application at hand will determine the most appropriate algorithm to use. Moreover, the target and terrain type often dictate which method will generate the most accurate results.

The write-function memory insertion technique involves identifying individual bands of data from different dates with certain primary colors, i.e. red, blue, and green. The different bands of data can then be overlaid to distinguish areas of change by the colors that result. For example, consider the case where one set of data is represented by the color red, while another set is represented by green. Equal intensities of red and green produce the color yellow and will indicate an area of no change. On the other hand, areas that did in fact change will exhibit either more red or more green shades of color. Using this process, two or three years of data can be examined for change detection, but the analysis does not specify the type of change or any from-to class information. It is, however, a quick method for gaining a general idea of the amount of change in a region. [15] Figure 1 depicts this arrangement.

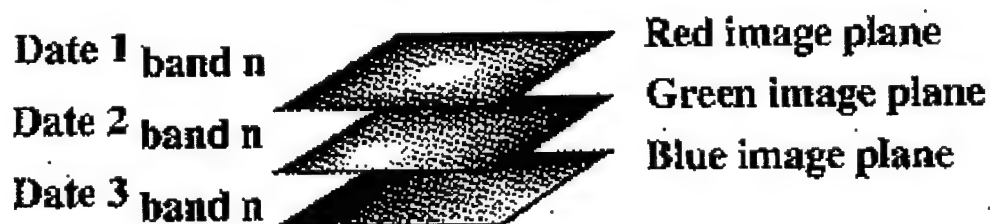
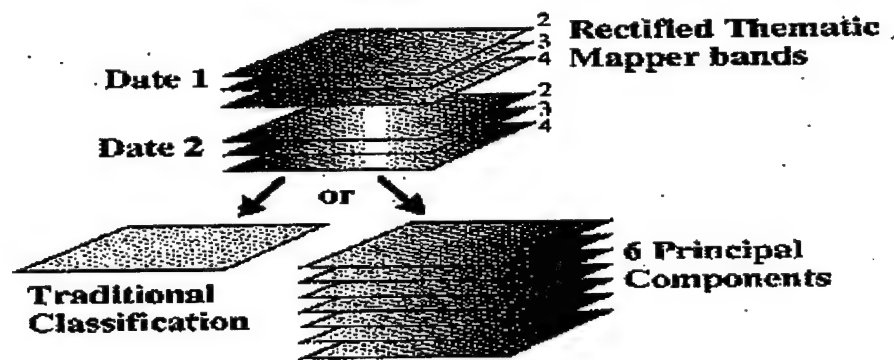


Figure 1. Multi-date Write-function Memory Insertion [15]

Direct multi-date change detection results from the analysis of a single set of data obtained by combining the data sets from two or more dates. After the individual data sets are rectified and then combined, an unsupervised classification can be used to identify change and no-change classes. Other analysis techniques may also be applied to the combined data set to ascertain change information depending on the requirements of the project. Coastal zone and forest changes [16] can often be determined using the multi-date composite image approach. The advantage of this method is that it requires only one classification. Nevertheless, like the write-function technique, it supplies no from-to class information and labeling the change classes can be a chore.



**Figure 2. Multi-date Composite Change Detection [15]**

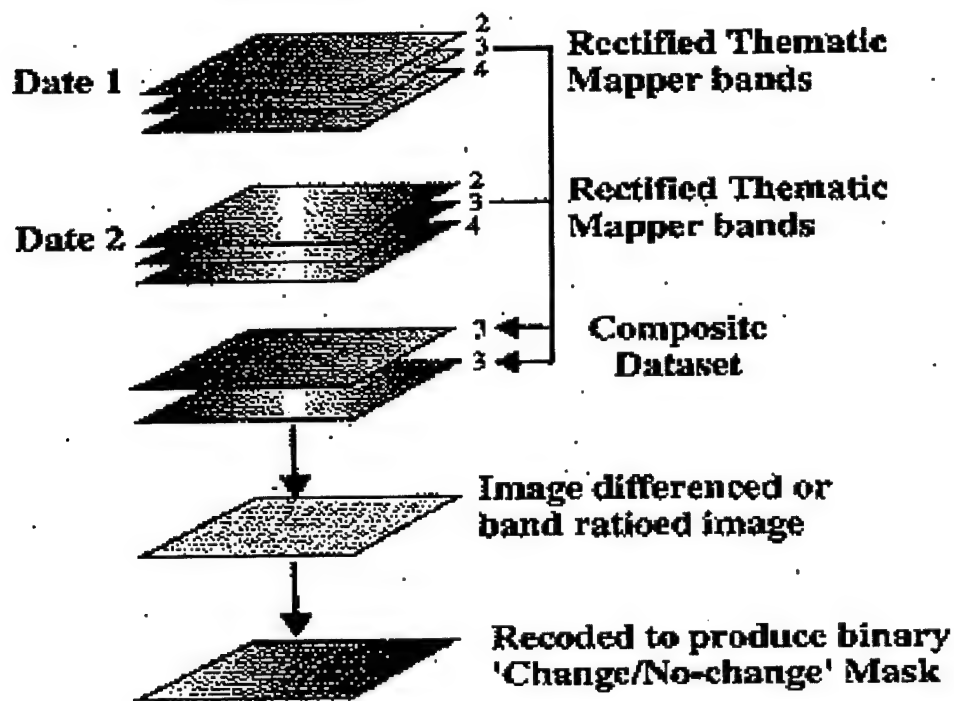
The quickest method of change detection described in the literature uses an overlay process involving image algebra. This procedure involves an overlay of TM data obtained on two different dates, generally utilizing TM band 3. The researchers at ERIM also developed an overlay formula using a linear combination of selected TM bands [17]. Using the IDRISI software, the OVERLAY procedure may involve either image differencing or image ratioing. The simplicity of both of these methods leads to their popular status among change detection techniques.

Image differencing relies upon the differences between corresponding pixel values to indicate areas of change. Large values that result from calculating the absolute value of the difference between corresponding pixels point to regions of change. When graphed, the pixel values displaying significant change should lie in the tails of the distribution, while all other values group around the mean [16]. Image differencing can be applied to both single and multiple bands of data. However, if necessary, radiometric corrections must be applied to the images before using the differencing technique. Land erosion, deforestation, and urban growth provide examples of subjects that lend themselves nicely to image differencing change detection.

Determining an appropriate difference map threshold embodies the true challenge of image differencing. A difference map threshold is a pre-determined value or range of values that measure whether the calculated difference in pixels indicates a change or no change. When choosing the threshold value the analyst must consider factors, such as fluctuating camera levels and viewing conditions, that may affect the outcome of the differencing. If the threshold is too low, the results of the change detection will be plagued by spurious changes. Likewise, an excessively high value may suppress significant changes. Therefore, choosing a threshold is a critical task when using image differencing.

Image ratioing resembles the differencing technique in its general simplicity; however, this technique calculates a ratio of the values of corresponding pixels from different images. If no significant change has occurred between two pixels, their values should be similar and the ratio will be approximately equal to one. If significant change has occurred, the ratio will be either much larger or much less than one. The advantage

of this technique is that, regardless of scene illumination variations, the image of ratios will still convey spectral or color characteristics of the features in the image. However, Lillesand and Kiefer caution the analyst to remember that images produced by ratioing are “intensity blind.” This means that materials that actually have distinct absolute radiances may appear similar if the ratio of their spectral values is similar—this occurs when the slope of their spectral reflectance curves are alike. [12] Therefore, as with all of the techniques described here, care must be taken to avoid making unfounded conclusions based on misleading data. Figure 3 illustrates the image algebra configuration--both the differencing and ratioing options apply.



**Figure 3. Image Algebra Change Detection [15]**

Multi-spectral images can also be analyzed with a technique known as change vector analysis. This method of change detection creates a vector space with the same number of dimensions as there are spectral bands being used. A vector representation of

each pixel can then be created using the brightness values of the pixels in each spectral dimension as their coordinates. If a pixel changes between the first and second image, the spectral change vector can be found by subtracting the two vectors that represent the pixel at the two times [18]. This technique allows for the calculation of both the magnitude and the direction of the change vector. However, the direction can only be determined if two spectral bands are involved in the analysis. Like image algebra, this technique also requires the determination of a threshold for the magnitude of the calculated change vector in order to define whether change has or has not occurred.

Change detection using the post-classification technique requires the classification of each image that will be used in the analysis. After classifying each image independently, a comparison can be made either visually or using a computer to identify areas of significant change. Visual interpretation may reduce registration errors since the human eye can discriminate patterns and shapes; however, a computer may provide a better quantitative analysis [16]. The analyst must decide which method best fits the given study. The overriding disadvantage of this method is the possibility of compounded errors due to multiple classifications. Any misclassification that occurs in the preliminary classifications will be compounded with subsequent applications. In fact, the overall accuracy can be calculated by multiplying the accuracy of each individual classified image. The advantage of making individual classifications, however, is that the analysis provides from-to class information. Examples of post-classification analysis applications include urban changes, forest to crop land changes, and general land use changes.

The following table summarizes the change detection techniques.

CHANGE DETECTION METHOD	ADVANTAGE(S)	DISADVANTAGE(S)
Write-Function Memory Insertion	<ul style="list-style-type: none"> <li>• Visual examination of two or three years of data</li> </ul>	<ul style="list-style-type: none"> <li>• No from-to class information</li> </ul>
Direct Multi-date Composite Image	<ul style="list-style-type: none"> <li>• Only requires one classification</li> </ul>	<ul style="list-style-type: none"> <li>• No from-to class information</li> <li>• May be hard to label change classes</li> </ul>
Image Algebra	<ul style="list-style-type: none"> <li>• Efficient method of identifying pixels which have changed in value</li> <li>• Simple to apply to a variety of image combinations</li> </ul>	<ul style="list-style-type: none"> <li>• No from-to class information</li> <li>• Must determine appropriate threshold</li> </ul>
Change Vector Analysis	<ul style="list-style-type: none"> <li>• Can determine direction and magnitude of change</li> <li>• Easily applied to more than one spectral band at a time</li> </ul>	<ul style="list-style-type: none"> <li>• Must determine appropriate threshold</li> </ul>
Post-classification	<ul style="list-style-type: none"> <li>• From-to class information</li> </ul>	<ul style="list-style-type: none"> <li>• Overall accuracy depends on individual classification accuracy</li> <li>• Requires more than one classification</li> </ul>
Ancillary Data Source	<ul style="list-style-type: none"> <li>• May reduce errors</li> <li>• From-to class information</li> <li>• Only requires one classification</li> </ul>	<ul style="list-style-type: none"> <li>• Depends on quality of ancillary data</li> </ul>

**Table 3. Change Detection Techniques**

### ***Image Classification***

Reliable change detection results depend upon an undistorted compilation of data. Ideally, the unaltered image information and pixel values are used for change detection. Nevertheless, many factors can falsify an image and, depending on the requirements of the change detection, image classification or correction may be necessary to enhance the

original data to create the change detection database. The goal of image classification is to employ any algorithm or collateral data, such as DEM's or soil maps, to improve the accuracy of the image [15]. There are two main types of image classification that will be described in further detail: supervised and unsupervised.

Supervised classification involves a training stage, when the analyst "trains" the classifier by supplying the criteria necessary for pixels from a single date to belong to known phenomena. A minimum-distance-to-means algorithm then places the pixels in their appropriate category and assigns unknown pixels to the nearest class or the class to which they have the highest probability of belonging. The training stage is of supreme importance because it is the building block of the classification and ultimately the change detection process. If the classified data are faulty, the change detection will also be incorrect.

Unsupervised classification relies upon the computer to inspect the data and identify a specified number of mutually exclusive clusters—groups of pixels that appear to exhibit the same spectral characteristics. Then, the analyst is left to determine the classes to which those clusters belong based on ancillary data or ground truth. This method of classification generally produces less accurate classifications than the supervised method; however, some studies may not have enough preliminary information to perform a supervised classification.

### ***Quality Assurance***

As with most scientific analyses, accuracy assessments often supplement remote sensing investigations to account for and analyze sources of error. To produce an accuracy assessment for a remote sensing application, the procedure generally requires

obtaining a “source of higher accuracy” [15] other than the remotely sensed images. Examples of sources include higher resolution photographs, verified field maps, or ground truth. Due to the inherent nature of change detection, accuracy assessments can often be impractical or unfeasible. Change detection usually involves images acquired over a length of time and, thus, actual field verification is often unavailable for past dates. Nevertheless, several quality assurance gauges will be described below since they may be applicable to change detection projects under the correct circumstances. Each of these accuracy measures is discussed in the C-CAP manual, along with others.

*Lineage* refers to the type of data sources used in the analysis and the operations involved in creating the database. As previously mentioned, the resolutions of the images and the dates of the materials should coincide. Using the same source of information and sensor type generally provides the easiest way to create these necessary conditions and reduce errors caused by lineage differences.

The *completeness* of an analysis refers to the extent to which the data addresses all possible combinations and conclusions. Classification data, for example, should include all categories present in the image. Furthermore, every pixel in an image should be assigned to one of the classes. Any missing data can potentially alter the results of a change detection analysis due to a lack of completeness.

The *fitness for use* gauge measures the degree to which the image and ancillary data actually relate to the application at hand. One of the first tasks before beginning any analysis requires that the data be assessed for its applicability to the study. Although a set of data may provide results, the results might not address the matter of concern and therefore are not fit for use.



*Attribute accuracy* estimates the probability that the land cover types given to each class in the image properly identify the actual land cover. According to the C-CAP manual, this accuracy measurement works best for studies involving current time periods and relatively small areas. The reason for these stipulations relates back to the earlier discussion of the applicability of accuracy measurements to change detection analyses in general. (Field verification cannot usually be obtained and large areas demand extensive, in-depth verification to be accurate.) Specifically, "accuracy assessments of large change databases are infeasible due to the combination of past time periods, large areas, and excessive from-to classes" [15]. Hence, when accuracy assessments prove to be impractical, the objective should be to **strive for consistency of technique more than accuracy.**

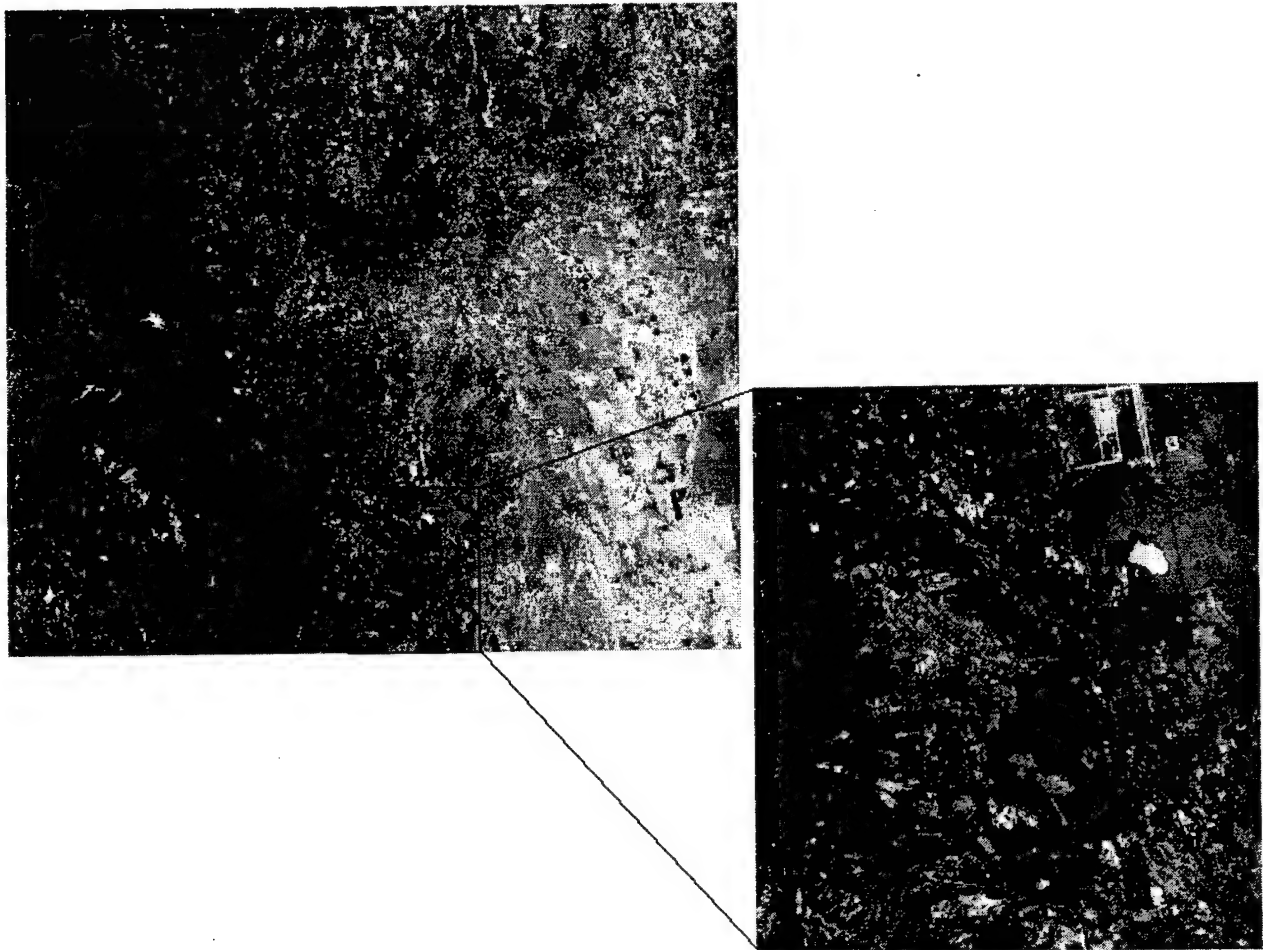
## ANALYSIS

### *Objective*

The aim of this investigation is to identify areas of significant change along Fountain Creek using satellite imagery and remote sensing methodology. For the purposes of this analysis, areas of significant change are areas where satellite sensors detect large differences in electromagnetic energy, resulting in large deviations in pixel values over time. The deliverables of the analysis will consist of images that offer a visual representation of the changes along Fountain Creek and in the surrounding study area.

The study area spans a stretch of Fountain Creek located just south of the metropolitan Colorado Springs area, to the west of the Colorado Springs airport, and to

the east of Fort Carson. This portion of the creek flows alongside Interstate 25, meandering randomly towards and away from the highway. The image below displays the region of study as it was cut from the larger LANDSAT image. Fountain Creek is the line shown crossing the smaller image from the upper left to the lower right.



**Figure 4. Fountain Creek Study Area**

#### ***GIS and Image Analysis Software***

The analysis is performed using the IDRISI software package developed by Clark University. IDRISI is a widely used GIS and image processing system that was introduced to the geographic and remote sensing industry in 1987. The IDRISI modules

utilized to register the images and perform the calculations include: WINDOW, COMPOSIT, CONCAT, OVERLAY, HISTO, SCALAR, RECLASS, and TRANSFOR. These modules permit a variety of image processing techniques, two of which will be presented here: image differencing and change vector analysis.

### ***Available Data***

Thematic Mapper imagery is collected regularly by LANDSAT satellites and provides a convenient source of data to detect changes over large areas. The following list describes the digital satellite imagery from LANDSAT that was used for the Fountain Creek analysis:

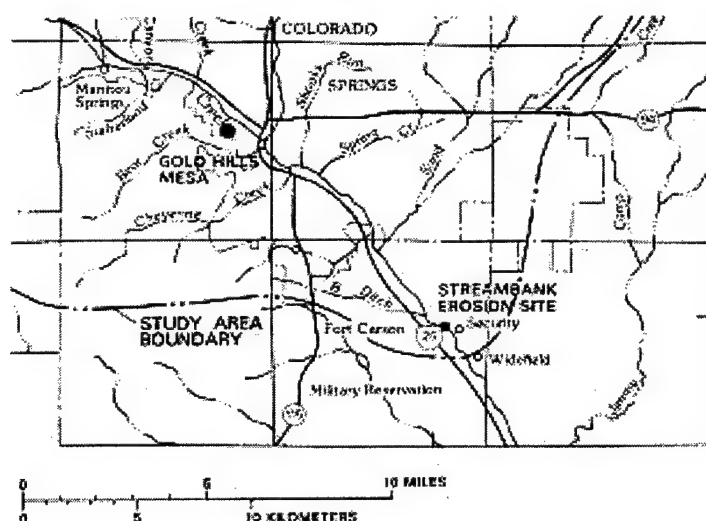
- Three sets of LANDSAT TM data including files for all seven spectral bands-- blue, green, red, near infrared, two mid-infrared, and one thermal infrared--for each image.
- **First Set:** April 1993
- **Second Set:** 4 July 1994
- **Third Set:** 26 June 1997
- The LANDSAT 5 (L5) satellite acquired each image.

A USGS map of the Colorado Springs area was also used to locate landmark sites to help verify the location of Fountain Creek and to gain a perspective for resizing the images for analysis.

### ***Expected Results***

Based on past research of the Fountain Creek region and the written and visual information provided by the Fountain Creek Watershed Project and the United States Geological Survey, significant areas of change should be visible along Fountain Creek. Case studies suggest that certain stretches of land along the creek demonstrate more vulnerability to erosion than others and, in fact, have the potential to change drastically overnight. The most vulnerable regions should therefore exhibit the most visible changes

in the change detection process and, because the analysis utilizes differences in raw pixel values, those areas should provide the best opportunity for accurate change assessments. To set the stage for the analysis, the following picture shows a region of Fountain Creek used in a study conducted by USGS—this same area corresponds well to the area used in this investigation. Note the dot on the map labeled as an erosion site.



**Figure 5.** Portion of USGS study that corresponds to this investigation. [5]

### ***Resizing and Registering the Images***

The first step of the analysis required resizing the images to acquire a workable view of the Fountain Creek region. The initial cut of the images involved determining the relative offsets between the images. The locations (rows and columns) of easily identifiable landmarks, GCPs such as water and buildings, were recorded and used to calculate the images' offsets. The 1997 image was cropped first to the desired size and set as the base image. Then, the other two images were resized based on their row and column deviations from 1997. After registering the images to a workable size, the images were cropped once again to obtain a smaller image that encompasses the Fountain

Creek region of interest. The selected area provides a region where the creek can be easily distinguished from its surroundings (See Figure 4).

Ideally, no more than a  $\frac{1}{4}$  to  $\frac{1}{2}$  pixel offset should exist between registered images for accurate results. Therefore, to ensure that the images were registered with minimal pixel offsets, the CONCAT function was used to overlay the images as if they were transparencies. The resulting image, shown in Appendix A, provides a visual representation of the deviations in the original images. The CONCAT image shows minimal distortion, with clearly visible landscape features, indicating that the cropped images correspond well. If the images did not correspond, the CONCAT image would have appeared more skewed and distorted.

The image enhancement and image correction capabilities of IDRISI were also explored, using the RADIANCE and RESAMPLE modules, respectively, but the altered images were not used in the analysis for several reasons. First, the resource that discusses the radiance correction module gives a very brief description of its use, with no reference to the actual calculations performed. Furthermore, the descriptive information provided with the images affirms that the images were acquired with similar sun angles, reducing the effects of sun angle variations. Above all, however, the desire to maintain the original pixel values for the calculations in order to avoid altering the data and skewing the results drove the decision to use the raw images.

### ***Differencing with Composite Images***

The first set of difference images was created using a combination of three corresponding spectral bands from each date. The combination of bands enhances the visibility of the creek without altering the pixel values. Three different composite images

for each date were created using the COMPOSIT module. The first composite set involves bands 3, 4, and 5. The IDRISI handbook suggests using this combination of bands for any general analysis. The second composite image involves bands 4, 5, and 7, and the third combination is made up of bands 3, 5, and 7. All of the composite combinations correspond to the blue, green, and red bands, in that order.

One reason for choosing the given combinations is that water strongly absorbs infrared wavelengths making it highly distinguishable in that region. The infrared bands therefore highlight the creek since its water reflects less light than the surrounding soil, vegetation, and concrete. It should be noted however that extra sediment in the water on any given date reflects more light than clear water. Also, the turbidity of the water affects the water's reflectance properties. Furthermore, while LANDSAT TM Band 5 is placed between two water absorption bands making it very useful in determining soil moisture differences, the calculated changes may be based on soil moisture rather than actual differences in landscape due to erosion. Thus, while the band combinations were chosen for their beneficial characteristics, the potential sources of error that they present must not be overlooked. For further clarification of the combination choices, refer back to Table 2.

Once the composite images were created, the OVERLAY module was used to perform the image differencing. Difference images were created for each pair of dates—1997/1994, 1994/1993, 1997/1993 (subtracting the earlier date from the later date)—with all three composite combinations. A histogram of each difference image was created using the HISTO module to display the spread of pixel values that resulted from the differencing procedure. For each of the images, the pixel values generally spread from

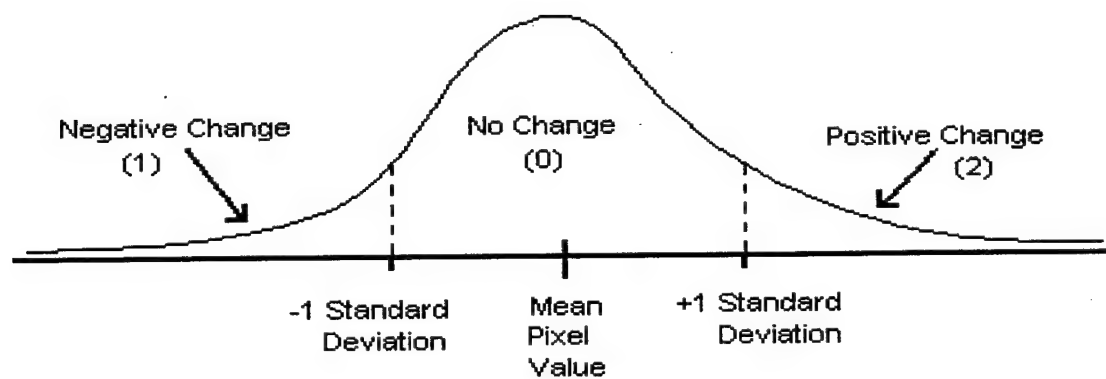
-215 to +215. Then, for display purposes, the SCALAR module was used to generate all positive DNs. This module simply adds a specified integer value to each of the original DNs. The final difference images, displayed with the gray 256 palette, and several of their corresponding histograms are shown in Appendix B. Note that the histograms for the composite images show several peaks in the data distribution, but the overall shape resembles a normal distribution around the mean. The various peaks are believed to be a result of using more than one band of data.

At this point in the study, the gray scale images display the areas of change based on the relative values of the pixels. The highest DNs correspond to the lightest areas in the image. These areas signify that the values from the earlier date were relatively small compared to the later date's values. Likewise, regions with the lowest DNs correspond to the darkest areas in the image, and indicate that the pixel values on the earlier image were much higher than the values on the later image in that region.

The next step was to calculate threshold values for the change in each image. There are no distinct guidelines for selecting threshold values, however image histograms are often used as an aid. The histograms provide statistical data about the images such as the mean and standard deviation of the pixel values. While the needs of each application may vary, one standard deviation is generally considered to be a reasonable threshold for determining positive, negative, and no change conditions. As such, the threshold values used in this study were one standard deviation on either side of the mean.

With the threshold values determined, the RECLASS module was used to create images that display the three levels of change. A value of zero was assigned to all DNs in the difference images that were within one standard deviation of the mean. This means

that there were no significantly visible changes in those areas. A value of one was given to pixels that demonstrated change in the range to the left of one standard deviation from the mean, negative change. Finally, a value of two signified all pixels that exhibited a change falling to the right of one standard deviation from the mean, positive change. The diagram below illustrates this arrangement.



**Figure 6. RECLASS Pixel Assignment for Change Detection**

Note that the labels “negative” and “positive” change do not suggest the quality of the change, but simply demonstrate whether the change fell to the left or right of the mean. In other words, it shows whether the DN value from one image is greater or less than the corresponding DN value from the image being subtracted. The images generated with the RECLASS function consist of three colors, with black representing the areas of no change, green as the areas of negative change, and blue as the areas of positive change. The reclassified images are also shown in Appendix B. While the reclassified images do indeed indicate areas of relatively high change, it is difficult to positively define the cause of the change.



### ***Single Band Image Differencing***

Single band difference images were also created to compare to the composite difference images. Bands 5 and 7 were used to create individual band difference images between the three dates. The same steps as described for the composite images—using the OVERLAY, WINDOW, HISTO, SCALAR, and RECLASS modules—were used, but with only one band from each date instead of three. The single band difference images and their histograms are given in Appendix C. Like the histograms for the composite images, the histograms for the single band images take on the shape of a normal distribution about the mean. However, for the single band difference images, there are only single peaks in the data distributions—likely the result of comparing only one band.

The single band difference images can be interpreted the same as the composite images. No new information is revealed in these images, but they do provide a broken down view of the changes by spectral band.

### ***Change Vector Analysis***

Change vector images were created using two bands—Bands 5 and 7—from each date. First, the single band difference images were squared using the TRANSFOR function, working with only two of the dates at a time. Those images were then added using OVERLAY. The final image resulted from taking the square root of the image sum using the TRANSFOR function once again. See the change vector images in Appendix D. The colors in the change vector images—displayed using the Idrisi 256 palette--represent the magnitude of the change vector. Dark blacks and blues signify areas of low

change. Shades of red show intermediate change, and yellows and greens indicate areas with a high magnitude of change.

### *Discussion of Images*

The main area of concern for this investigation is the creek that flows diagonally from upper left to lower right in the images. While inferences can be made about other areas appearing in the images, they will not be addressed here. Also note that the clouds in the 1997 image, which appear on the left side of the images involving 1997 in the calculations, must not be considered in the analysis. In addition, due to the many factors that can skew the results of a purely mathematical analysis, many of the inferences made from the images result from a purely visual comparison and interpretation.

The images created with the differencing procedure do indeed display the expected change along Fountain Creek and expose areas that demonstrate the greatest relative change. The light and dark shades in the gray scale images indicate the degree to which regions of the creek have changed according to raw pixel values. The reclassified images, on the other hand, provide a more clear cut representation of the areas that demonstrate the greatest probability to have changed and the general direction of the change, i.e. whether the smaller DN came from the earlier date or the later date. Smaller DNs could be the result of wetter soil since water reflects less in the infrared. Hence, if the smaller DN came from the earlier date—resulting in positive change--the soil could have become drier as the creek cut further into the land and away from the area, increasing the DN value on the later date. On the other hand, if the smaller DN came from the later date—resulting in a negative change—the creek may have eroded the land and started to flow over it. Nevertheless, the exact cause of the detected change is

uncertain due to the many factors detailed throughout the paper that affect pixel values. The suggestions presented here offer just one possible interpretation.

The change vector images seem to offer the best indication of which areas along Fountain Creek have undergone the greatest change. The areas defined in yellow are less frequent than the large areas of change displayed in the reclassified images previously mentioned. These yellow areas also lie right along the creek's edge, suggesting that they may be the result of heavy erosion. In the vector change analysis between 1994 and 1993, there appears to be a large amount of intermediate change right along the creek with some higher magnitude of change areas highlighted in yellow. The yellow areas often appear in large meanders of the creek where the creek's flow would tend to cut into the land—in a natural attempt to flow in a straight line. A comparison of the gray scale images to the change vector images helps identify the exact location of the areas that indicate the heaviest change.

### ***Limitations***

Due to the limited resources available for this study, the results of the analysis must be understood within the big picture. The LANDSAT TM images provide a 30 x 30-meter resolution as already mentioned. This means that the changes detected reside in this range of measurement and larger. Changes on a smaller scale are immeasurable with the available images. Thus, the image calculations give a rough magnitude of the changes around Fountain Creek. Also, the available images were not taken on exact anniversary dates. As explained earlier, this can create offsets between images leading to false change detection due to sun angle differences, moisture differences, etc. Furthermore, because Fountain Creek takes up a very small, barely defined portion of the

raw images provided by LANDSAT, the images were cropped to facilitate the analysis of the specified region. The locations of major landmarks in the three sets of images did not correspond pixel for pixel. Hence, the cropping procedure involved cutting the images to the closest pixel to pixel correspondence possible. This means that error may have been introduced in the image registration process if the pixels from each date do not perfectly coincide. Much care was taken to ensure the best fit; however, more care must be taken not to overlook this possible source of error.

With a more in-depth analysis of the geography and ground cover of the region, these images may help verify which zones along the creek demonstrate more vulnerability to erosion. Unfortunately, digital elevation models were unavailable to perform a change analysis on the elevations in the area. This type of analysis would help verify if the changes detected in the spectral analysis are due to changes in ground elevation caused by erosion or whether other factors affected the results of the change analysis. Furthermore, the many external factors that influence the image processing calculations complicate the calculation of reliable figures to describe the changes along Fountain Creek. In addition, because the changes along Fountain Creek could potentially go undetected within the resolution of LANDSAT TM imagery, a more specific quantitative analysis of the change would be counterproductive. However, while aerial photography, which can also be used for remote sensing analyses, is less convenient to use, is not collected on a regular basis, and is more costly, it may provide the means to perform a more quantitative analysis in the future.

## CONCLUSION

Satellite remote sensing and GIS technology are the key to gaining a keener insight into the erosive processes at work on the Earth's surface. Analyses that are committed to taking full advantage of the enhanced satellite and GIS technology can help explain how human activities throw the Earth's natural processes out of balance. Moreover, a better understanding of erosion may aid in the careful placement of new pavement and buildings as well as improve the current resource management procedures. This could ultimately lead to a fewer number of dilemmas in the future.

This investigation in particular was performed as a part of a research proposal submitted to NASA for the study of the erosion and pollution problems of the Fountain Creek Watershed. The images presented in the analysis provide a visual representation of the areas that display the greatest change. Although the results of this study do not provide solutions to the erosion problem, the information provided and the images generated act as a stepping stone to support further studies of the area.

**APPENDIX A**  
**TRANSPARENT CONCAT IMAGE**



Meters



0.03

Figure A1. Transparent CONCAT overlay of cropped images from 1993, 1994, and 1997.

**APPENDIX B**  
**COMPOSITE DIFFERENCE IMAGES**  
**AND RECLASSED IMAGES**





Figure B1. Composite difference image—Bands 3, 4, and 5-- for 1994 and 1993.

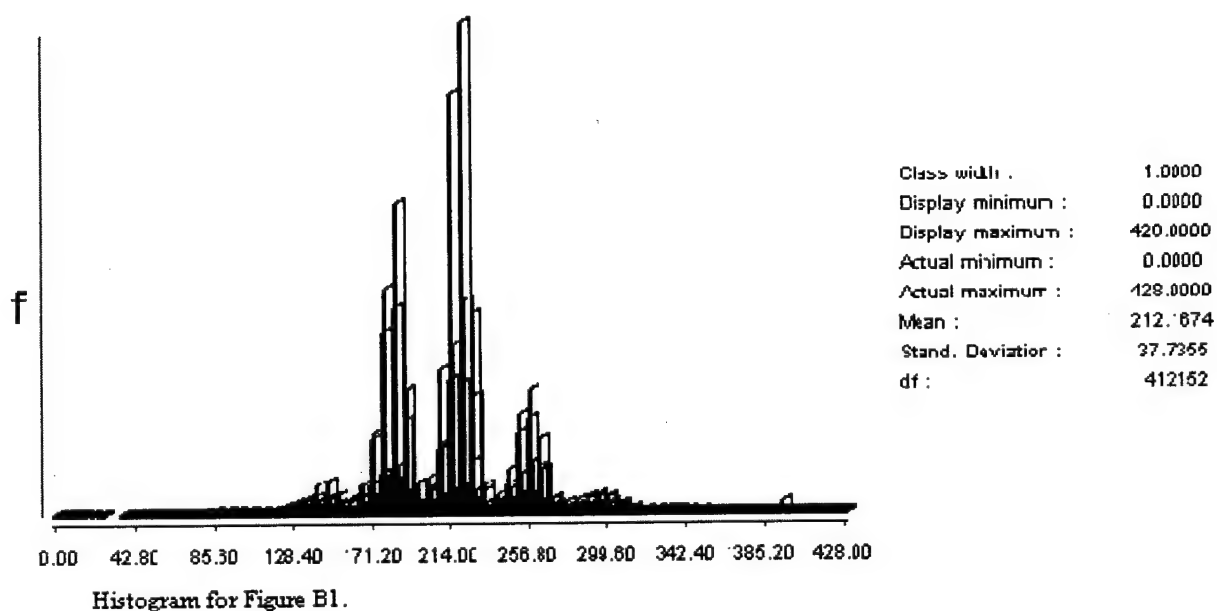
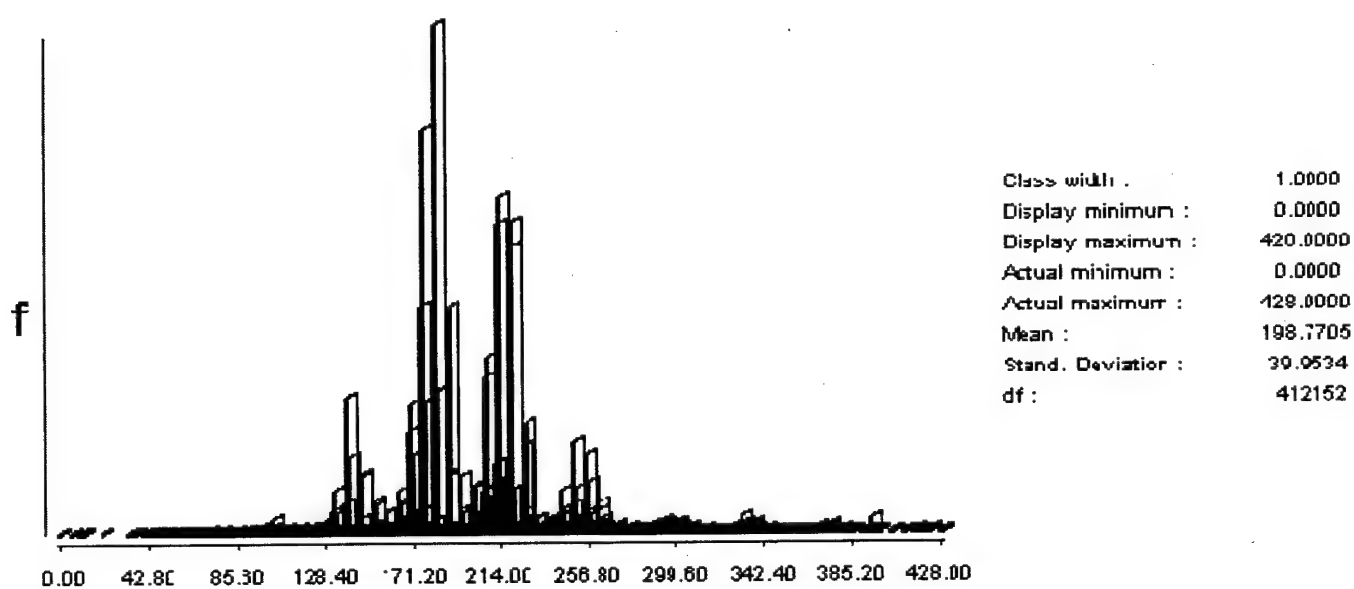




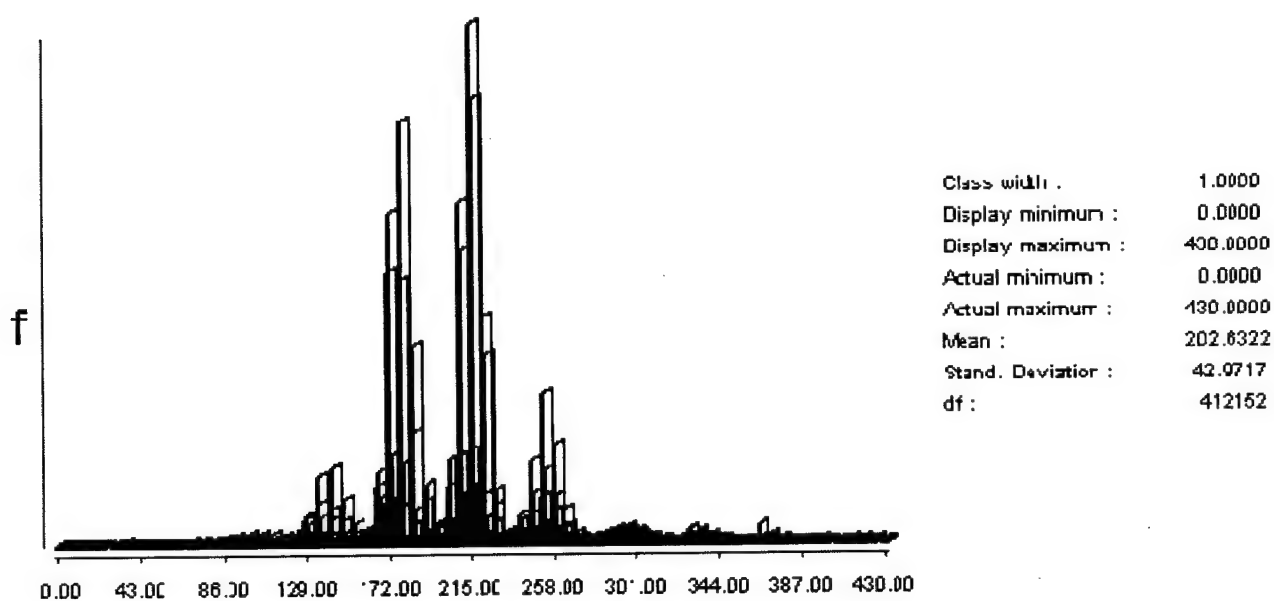
Figure B2. Composite difference image—Bands 3, 4, and 5—  
for 1997 and 1993.



Histogram for Figure B2.



Figure B3. Composite difference image—Bands 3, 4, and 5—for 1997 and 1994.



Histogram for Figure B3.



Figure B4. Composite difference image—Bands 4, 5, and 7—  
for 1994 and 1993.



Figure B5. Composite difference image—Bands 4, 5, and 7—  
for 1997 and 1993.



Figure B6. Composite difference image—Bands 4, 5, and 7—  
for 1997 and 1994.

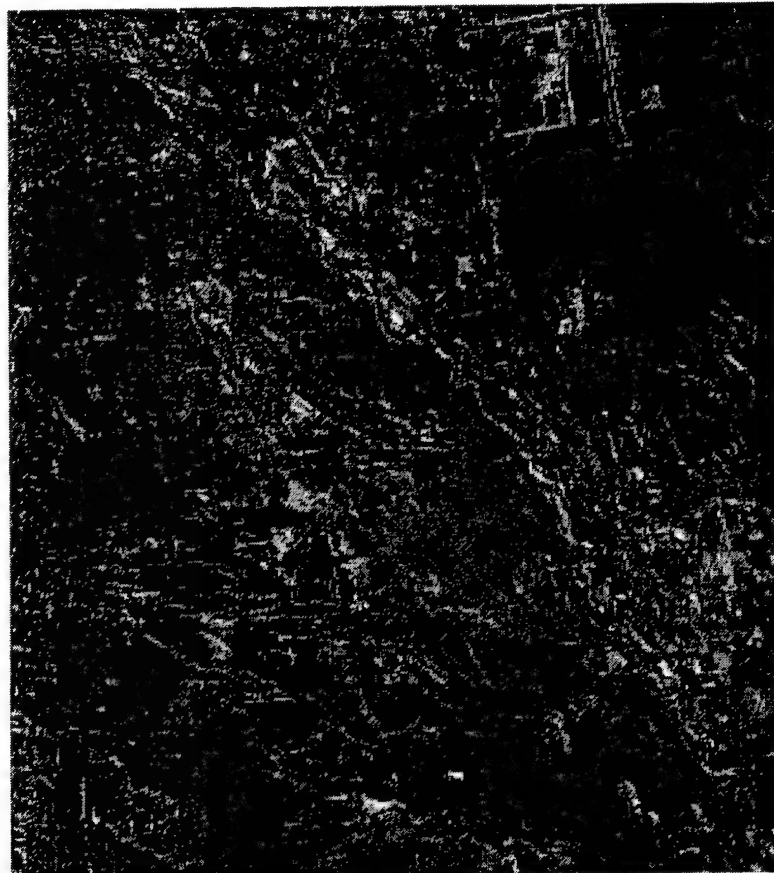


Figure B7. Composite difference image—Bands 3, 5, and 7—  
for 1994 and 1993.

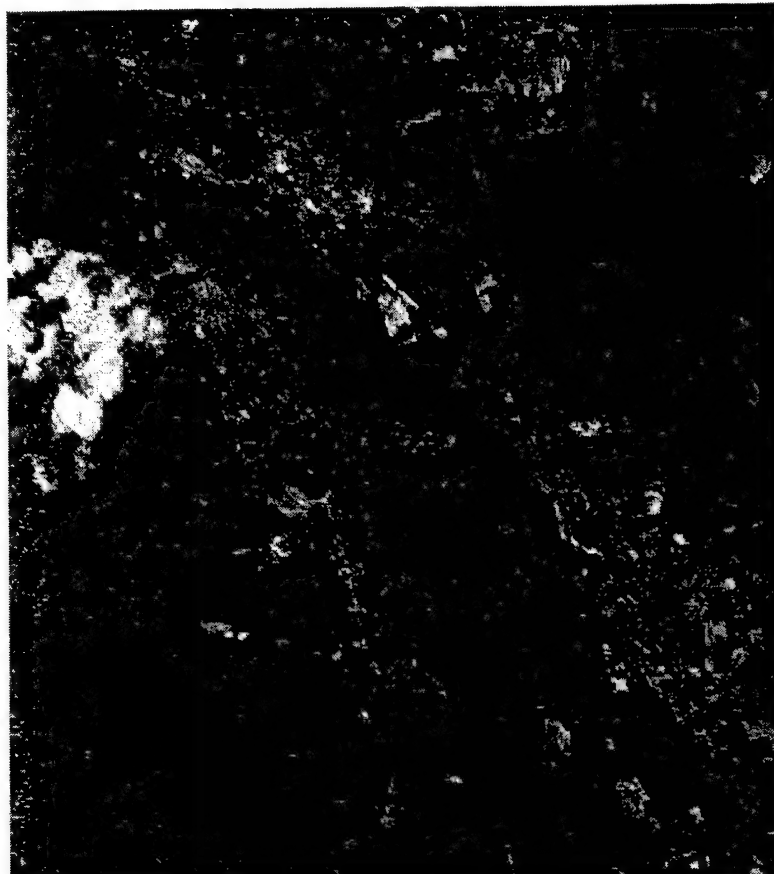


Figure B8. Composite difference image—Bands 3, 5, and 7—  
for 1997 and 1993.





Figure B9. Composite difference image—Bands 3, 5, and 7—  
for 1997 and 1994.



Figure B10. Reclassed image for 1994 and 1993 composite difference image (Bands 3, 4, and 5).

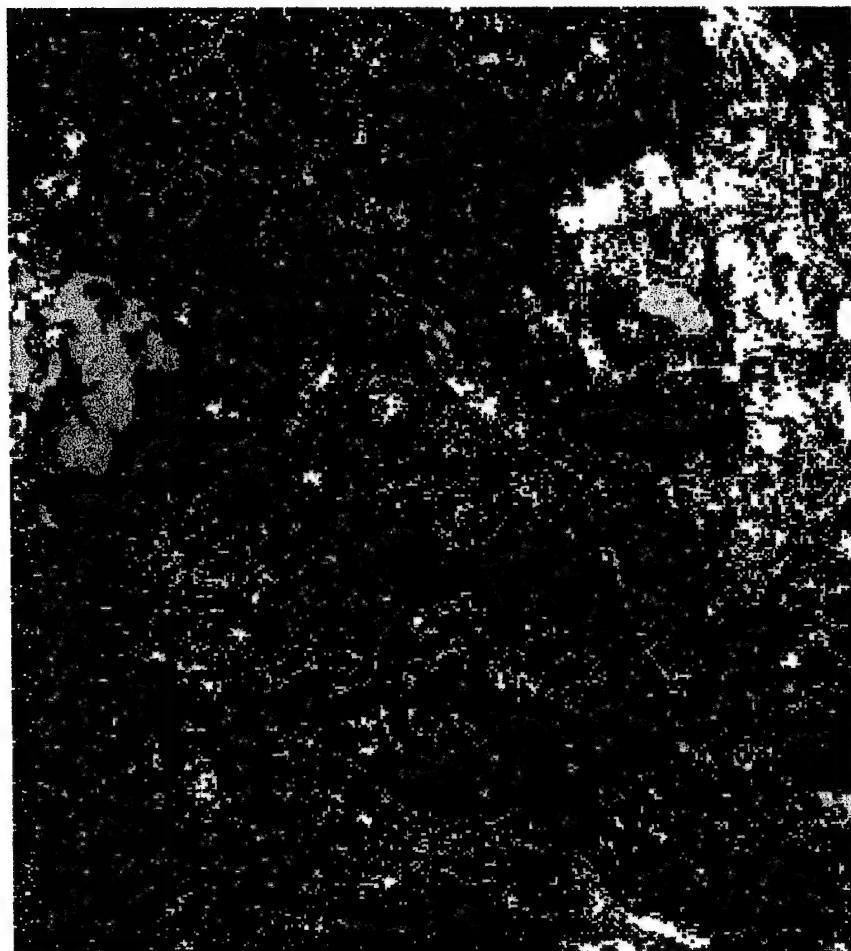


Figure B11. Reclassed image for 1997 and 1993 composite difference image (Bands 3, 4, and 5)

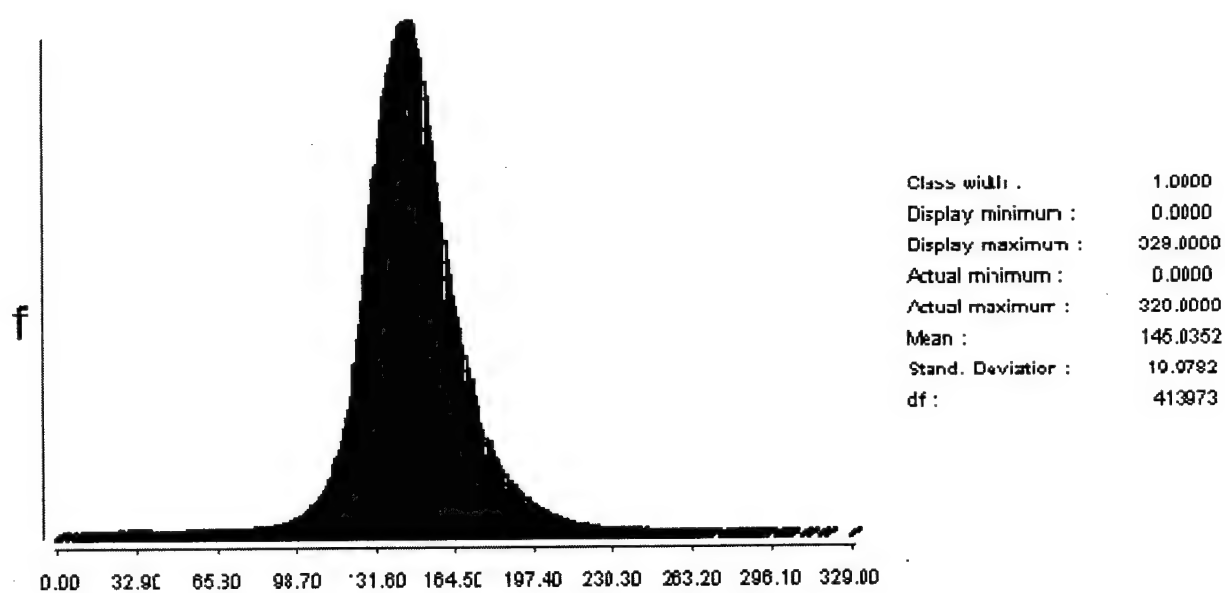


Figure B12. Reclassed image for 1997 and 1994 composite difference image (Bands 3, 4, 5)

**APPENDIX C**  
**SINGLE BAND DIFFERENCE IMAGES**  
**AND THEIR HISTOGRAMS**



Figure C1. Band 5 difference image for 1994 and 1993.



Histogram for Figure C1.

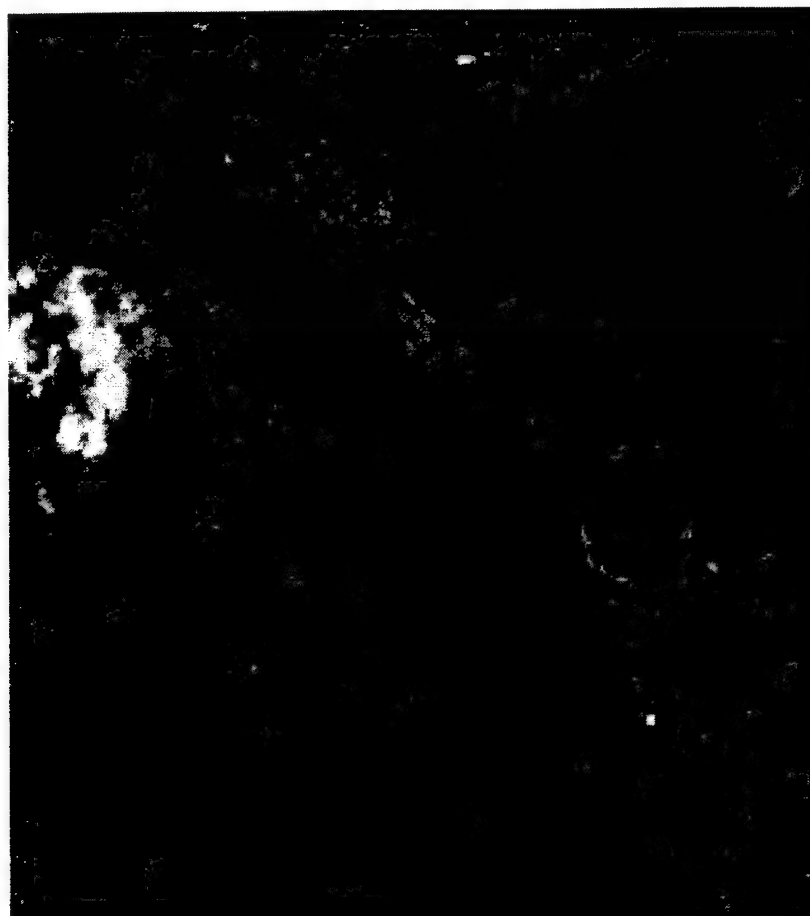
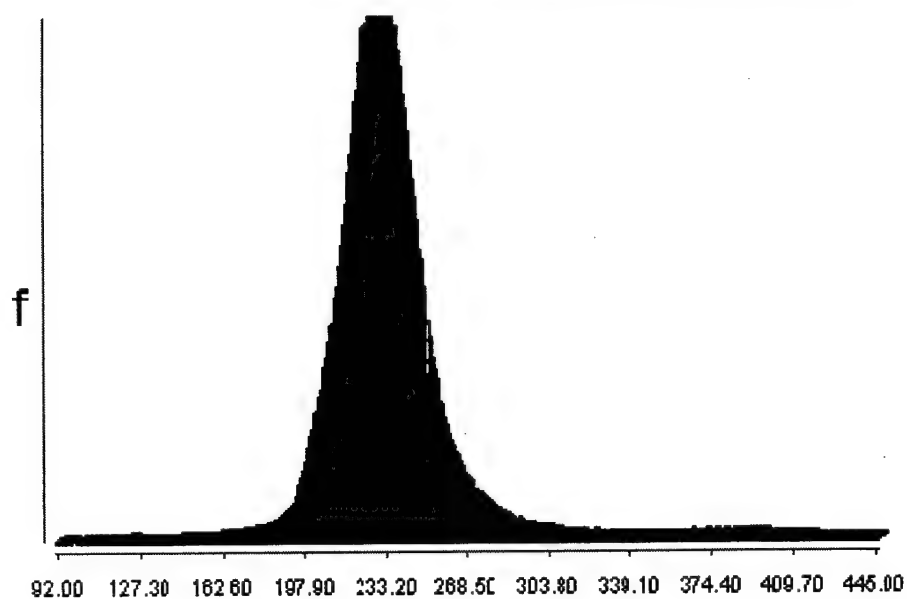


Figure C2. Band 5 difference image for 1997 and 1993.



Histogram for Figure C2.

Class width :	1.0000
Display minimum :	92.0000
Display maximum :	445.0000
Actual minimum :	92.0000
Actual maximum :	445.0000
Mean :	231.9334
Stand. Deviation :	25.4932
df :	414189

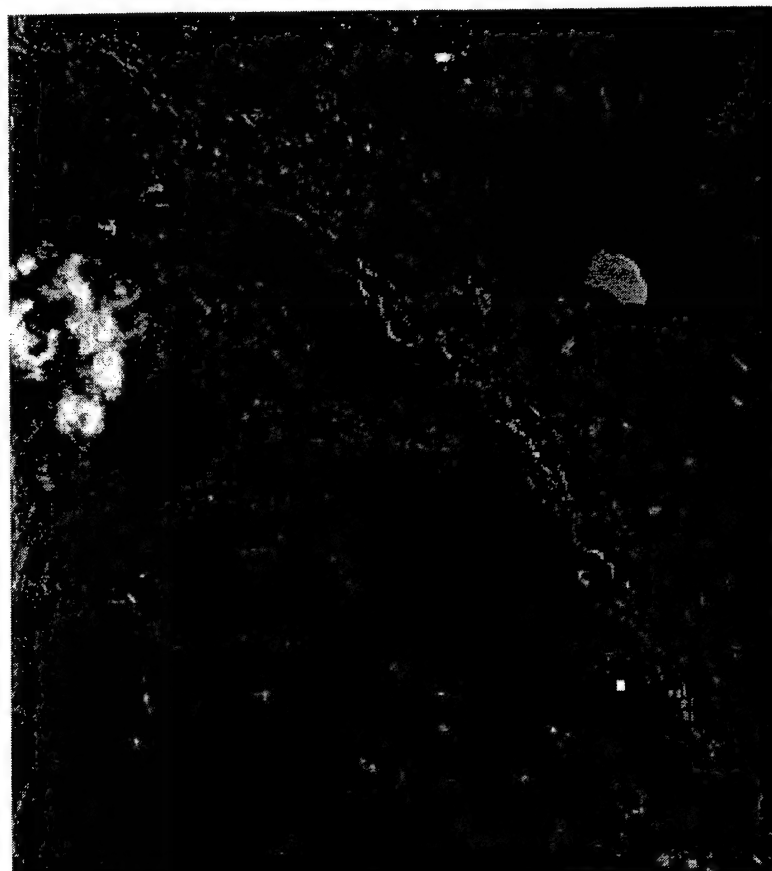
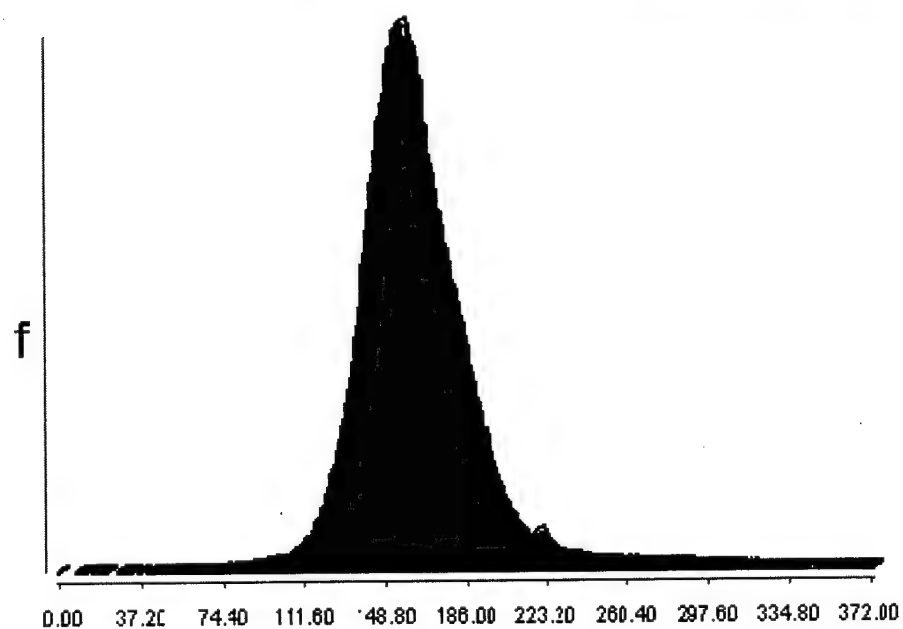


Figure C3. Band 5 difference image 1997 and 1994.



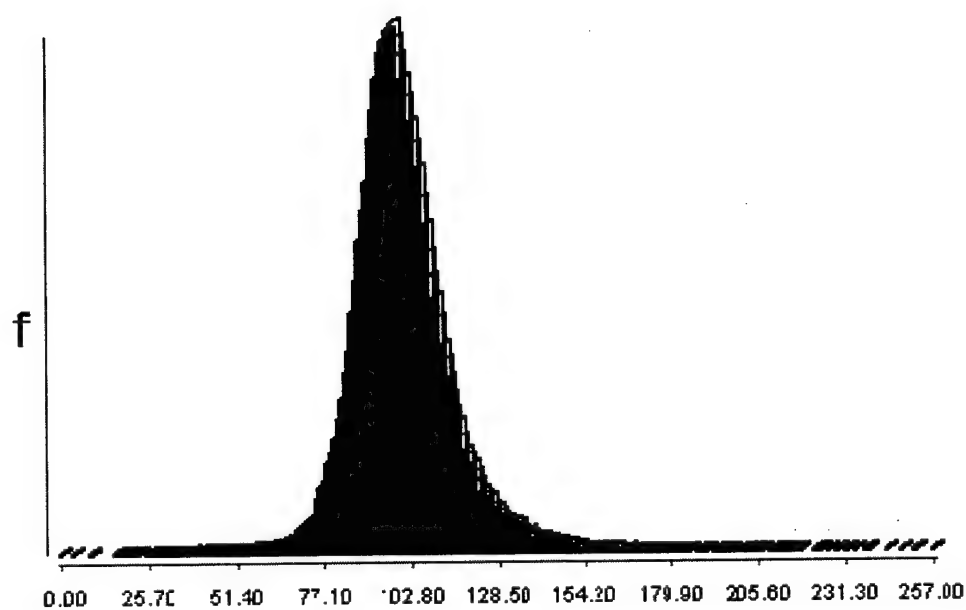
Class width :	1.0000
Display minimum :	0.0000
Display maximum :	372.0000
Actual minimum :	0.0000
Actual maximum :	372.0000
Mean :	160.8564
Stand. Deviation :	25.2230
df :	414189

Histogram for Figure C3.





Figure C4. Band 7 difference image for 1994 and 1993.



Histogram for Figure C4.

Class width :	1.0000
Display minimum :	0.0000
Display maximum :	257.0000
Actual minimum :	0.0000
Actual maximum :	257.0000
Mean :	98.9486
Stand. Deviation :	13.6369
df :	412152

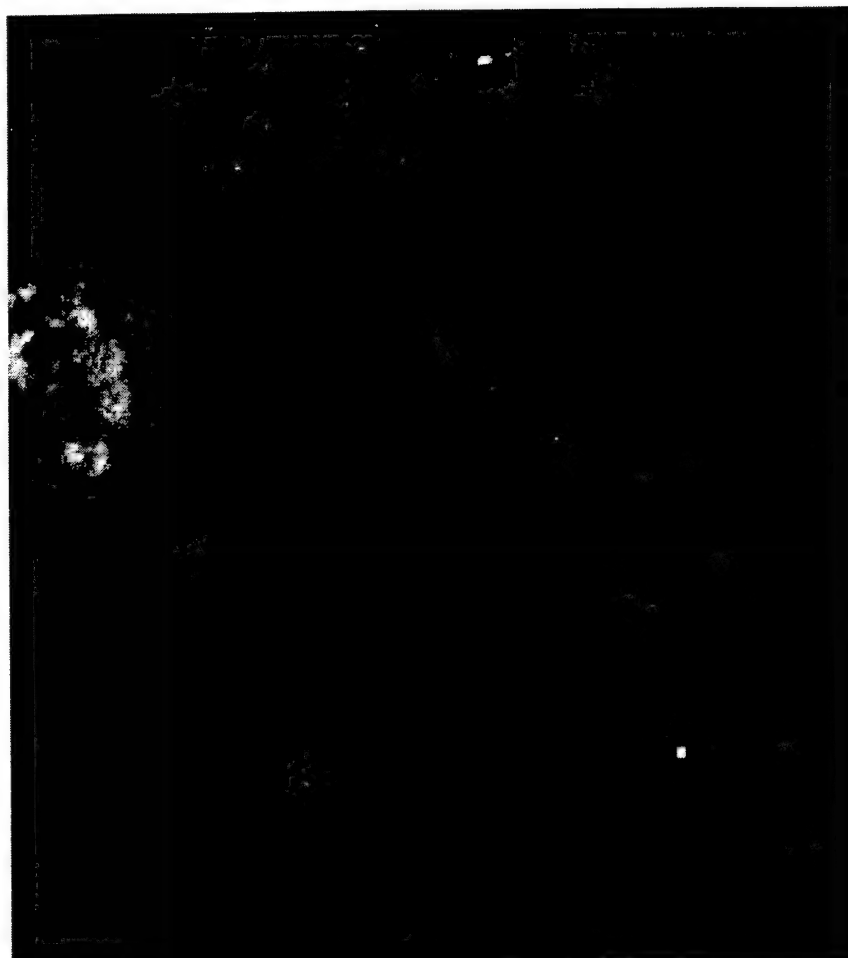
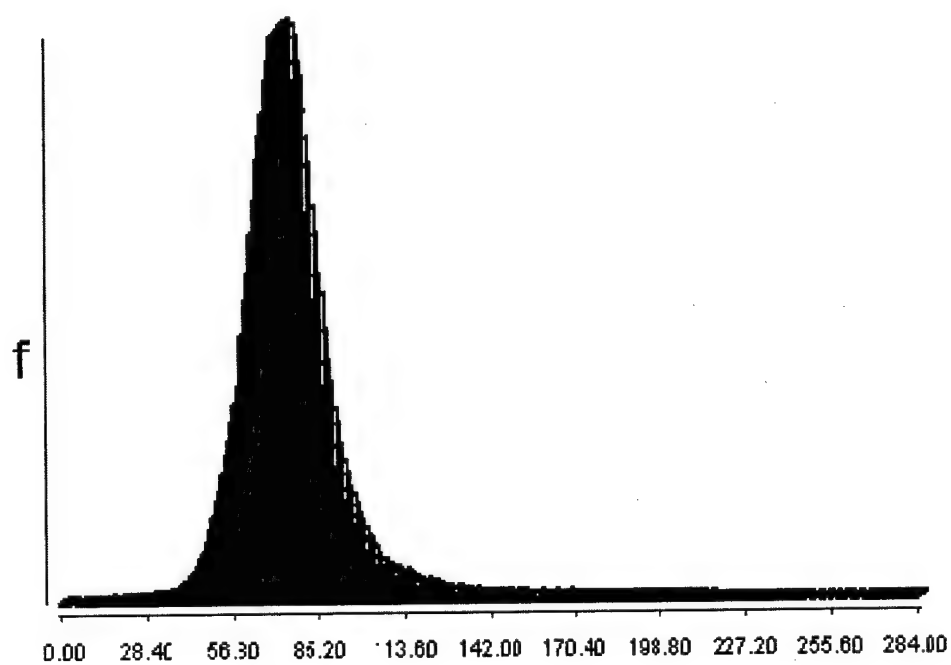


Figure C5. Band 7 difference image for 1997 and 1993.



Histogram for Figure C5.

Class width :	1.0000
Display minimum :	0.0000
Display maximum :	204.0000
Actual minimum :	0.0000
Actual maximum :	291.0000
Mean :	75.1644
Stand. Deviation :	18.5294
df :	414189

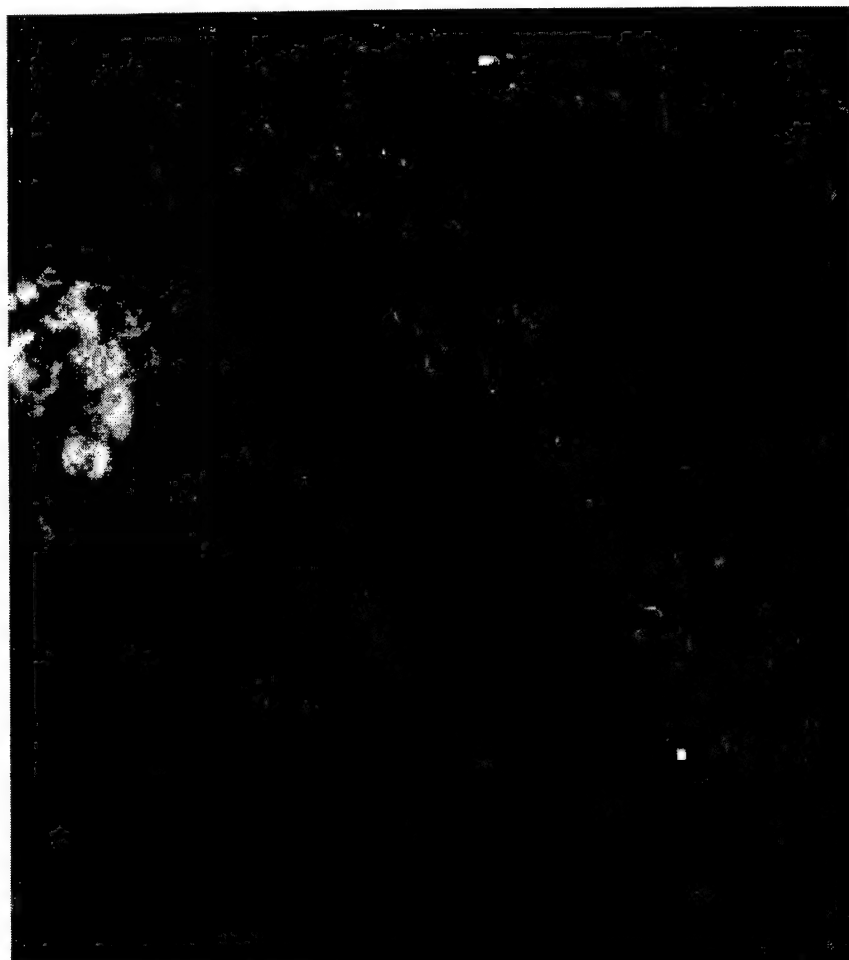
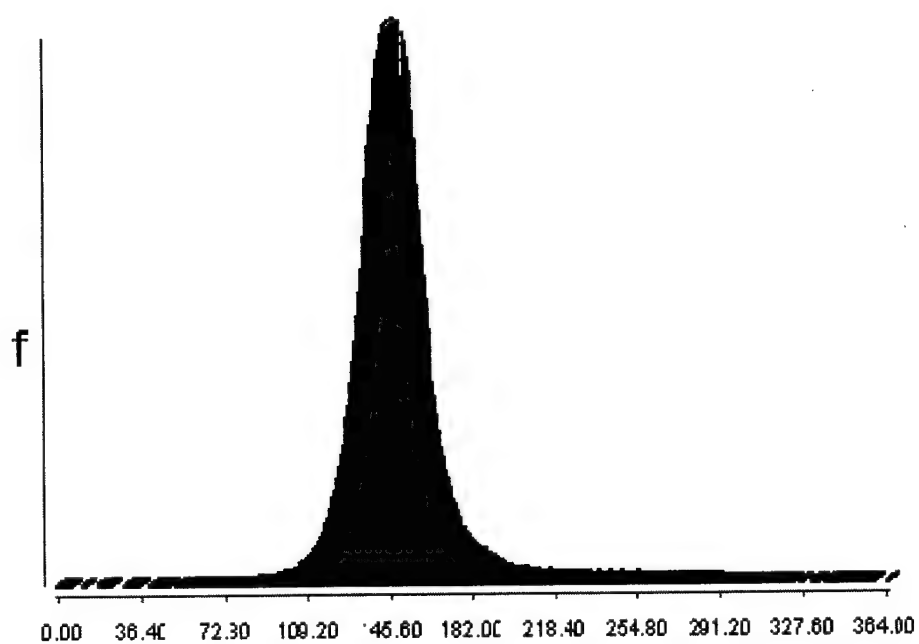


Figure C6. Band 7 difference image for 1997 and 1994.



Histogram for Figure C6.

Class width :	1.0000
Display minimum :	0.0000
Display maximum :	364.0000
Actual minimum :	0.0000
Actual maximum :	364.0000
Mean :	146.3135
Stand. Deviation :	19.6402
df :	414189

**APPENDIX D**  
**CHANGE VECTOR ANALYSIS IMAGES**



Figure D1. Change vector image for Bands 5 and 7 from 1994 and 1993.



Figure D2. Change vector image for Bands 5 and 7 from 1997 and 1993.

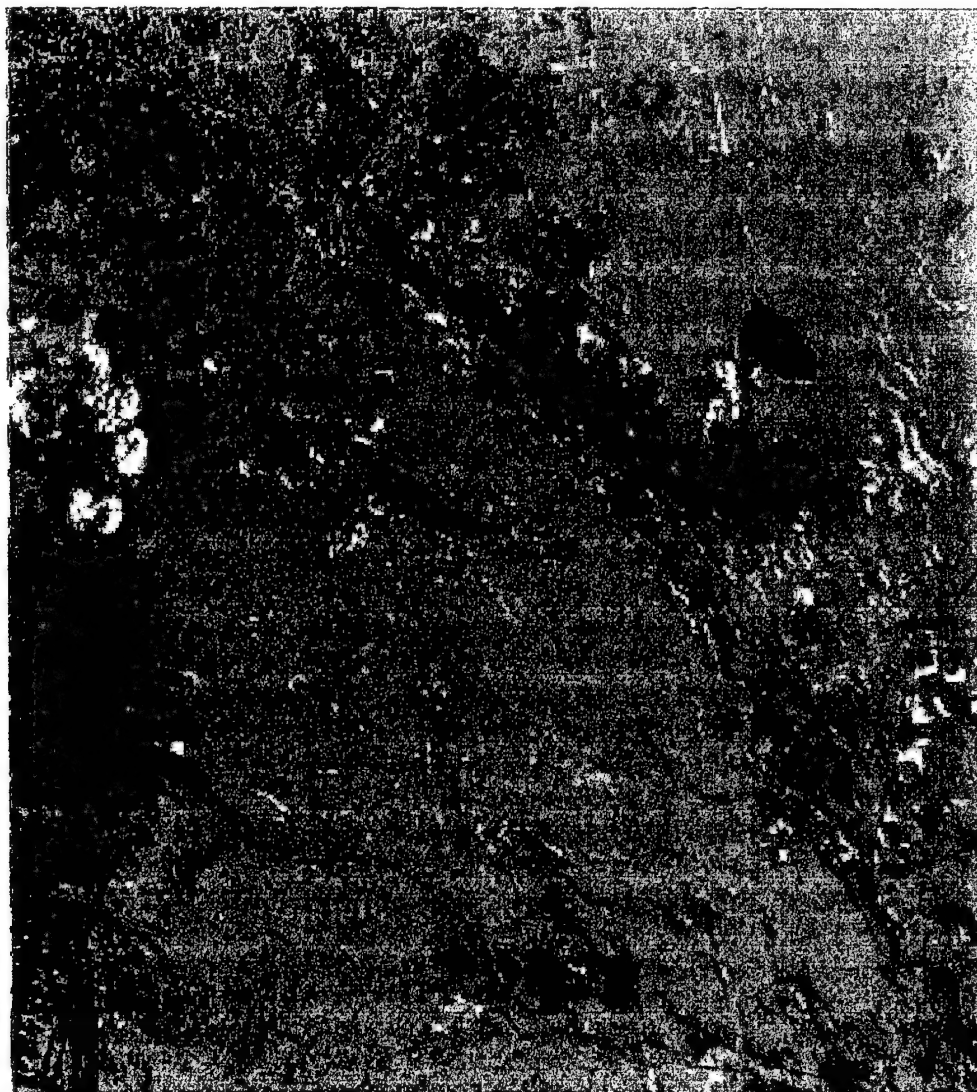


Figure D3. Change vector image for Bands 5 and 7 from 1997 and 1994.

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## **ABSTRACT**

Remote sensing methodology and GIS technology provide the resources needed to gain an improved understanding of the Earth as a system. Worldwide population growth and development amplify the naturally occurring changes on the Earth's surface and give birth to new types of changes. With the help of remote sensing technology, the energy radiated by surface features or reflected off the Earth's surface by the sun can be used to map the land and trace the changes that take place over time. GIS technology can then be used to integrate large amounts of image data and other related details about an area to analyze the changes and their origin.

This paper discusses the methodology and analytical techniques used to process digital images with a focus on change detection processes. It also emphasizes many of the atmospheric affects that must be considered before analysis can begin or inferences can be made. In addition, a change detection analysis of a region of Fountain Creek in Colorado Springs is performed using LANDSAT TM images gathered in 1993, 1994, and 1997. The analysis provides an example of the application of many of the techniques initially discussed and also highlights the cautions that were taken to avoid false conclusions. The investigation includes the generation of change detection images produced using image algebra and change vector analysis.

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Remote sensing methodology and GIS technology provide the resources needed to gain an improved understanding of the Earth as a system. Worldwide population growth and development amplify the naturally occurring changes on the Earth's surface and give birth to new types of changes. With the help of remote sensing technology, the energy radiated by surface features or reflected off the Earth's surface by the sun can be used to map the land and trace the changes that take place over time. GIS technology can then be used to integrate large amounts of image data and other related details about an area to analyze the changes and their origin.

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